IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of	**MAIL STOP AMENDMENT**
David J. Cooperberg et al.	Group Art Unit: 1763
Application No.: 10/024,208	Examiner: Luz L. Alejandro Mulero
Filed: December 21, 2001	Confirmation No.: 9076
For: TUNABLE MULTI-ZONE GAS INJECTION SYSTEM	

DECLARATION BY DAVID J. COOPERBERG UNDER 37 C.F.R. § 1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

1. I am an inventor of subject matter claimed in the above-identified application ("present application").

2. I received a Bachelor's degree in Applied and Engineering Physics from Cornell University in 1990, and a Ph.D. in Physics from the University of California at Berkeley in 1998. I am currently a Modeling and Sr. Process Engineer at Lam Research Corporation ("Lam") in Fremont, California. Lam is the assignee of the present application. I have worked at Lam since 1997. During this time, I have designed gas injectors and provided fluid dynamics and plasma discharge modeling support for product development. A list of my patents, published patent applications, technical publications and presentations is attached

3. I have reviewed International Publication No. WO 00/41212 to Ni et al. ("Ni"), which corresponds to U.S. Application No. 09/788,365 assigned to Lam. Based on this review, my knowledge of the design of the Ni gas injector at Lam, and my knowledge of gas injectors for semiconductor material plasma processing equipment, the Ni injector is useful for processes, such as metal etching, which can use a fixed center and edge flow pattern, but the plasma processing system claimed in the present application provides superior and unexpected results as compared to the Ni injector for multi-step etching.

4. In today's semiconductor manufacturing environment, it is necessary to vary gas compositions and flow rates during different fabrication steps in multi-step processes. Such steps can include, for example, ARC etch, photoresist etch, hardmask open, trench isolation and gate etch, which can be performed on a single substrate (wafer) in the same plasma processing chamber. During development of the present invention, it was found that the Ni injector would not meet the uniformity standards for such multi-step etch processes, wherein the gas composition and/or flow ratio is changed at least once.

5. The Ni injector shown in Figures 1 and 3A-3C includes a single bore 44 that is in fluid communication with each of the on- and off-axis gas outlets 46. A common gas is supplied to each on-axis and off-axis outlet 46 via the single bore 44. With extensive engineering design and experimentation, this Ni injector could be used to achieve a desired, fixed edge- and center-zone gas flow distribution (flow ratio) for a single-step etch process, such as aluminum etching. Consequently, the

Ni injector is impractical and cannot provide optimal process uniformity for some multi-step etch processes requiring strict uniformity standards.

6. The claimed plasma processing system includes a gas injector that provides dual-zone gas injection, i.e, center zone and edge zone gas injection, in the plasma processing chamber. The system includes an RF energy source for inductively coupling RF energy into the chamber to produce a plasma. The system includes a gas injector having at least one on-axis gas outlet and a plurality of off-axis gas outlets. The off-axis gas outlets can be adapted to inject process gas at an acute angle relative to a plane parallel to an exposed surface of a substrate supported on a substrate support within a processing chamber. The plasma processing system also includes a common gas supply in fluid communication with two different gas lines, wherein one gas line is in fluid communication with the on-axis outlet but not with the off-axis outlets, and the other gas line is in fluid communication with the off-axis outlets but not with the on-axis outlet. The system includes flow controllers that allow process gas to be supplied at flow rates that are independently varied between the on-axis and off-axis outlets, thereby allowing the gas injector to vary the flow ratio of a common gas mixture through the on-axis and off-axis outlets.

7. The claimed plasma processing system can be used to perform multi-step etch processes using a single injector design. That is, an injector designed with certain features, such as number of off-axis outlets, off-axis outlet orientation. off-axis outlet diameter and on-axis outlet diameter, can be used to perform multiple

steps of a multi-step process, in which the gas composition and/or flow ratio is changed at least once during the process, and meet uniformity standards. Consequently, the claimed gas injector is cost-effective with respect to design costs.

8. The present application includes Examples at pages 19-21 that demonstrate superior process results that can be provided by the claimed plasma processing system. As described in the Examples, the plasma processing system included an RF energy source for inductively coupling RF into the chamber to produce a plasma. The chamber included a dielectric window forming a wall of the chamber and the gas injector extended through the window. The gas injector used in the Examples included an on-axis outlet and off-axis outlets adapted to inject process gas at an acute angle relative to a plane parallel to an exposed surface of a substrate supported on a substrate support within the processing chamber. A common gas supply supplied process gas to the on- and off-axis outlets via separate gas lines. Flow controllers supplied the process gas from the common gas supply at flow rates that were independently varied between the on- and off-axis outlets into the processing chamber. The test results for Examples 1 to 3 are shown in the Table below.

Table

Example No.	Process	Predominately On-Axis Gas Flow Result	Predominately Off-Axis Gas Flow Result	Mixed Gas Flow Result
1	polysilicon etch	• etch depth of 212.9 ± 4.7 nm (± 2.2%) • range of 18.3 nm (± 1.4%)	• etch depth of 212.6 ± 5.3 nm (± 2.5%) • range of 22.3 nm (± 1.7%)	**• etch depth of 213.5 ± 2.3 nm (± 1.1%)** **• range of 7.7 nm (± 0.6%)**
2	silicon etch	• etch depth of 1299 ± 27 Å (± 2.1%) • range of 74 Å (± 1.0%)	**• etch depth of 1272 ± 14 Å (± 1.1%)** **• range of 41 Å (± 0.53%)**	• etch depth of 1295 ± 23 Å (± 1.8%) • range of 76 Å (± 1.0%)
3	polysilicon gate etch	• mean CD variation of -3.9 nm • standard deviation of 2.1 nm • range of 7.5 nm	**• mean CD variation of -3.4 nm** **• standard deviation of 1.6 nm** **• range of 5.9 nm**	

9. Specifications for etch rate and CD uniformity are continuously becoming more demanding. Requirements for etch rate can be < 2% (3 sigma) non-uniformity, i.e., more than 99.7% of the wafer surface etches at a rate which is within 2% of the mean etch rate. CD uniformity limits the etch contribution to non-uniformity to 1 to 2 nm. That is, the CDs (pre etch - post etch) measured at all locations on the wafer should be within a few nanometers of each other. The test results shown in Table 1 indicate that the best results were achieved in the polysilicon etch process of Example 1 using a mixed gas flow, while the best results were achieved in the silicon etch process of Example 2 and the polysilicon gate etch process of Example 3 using a predominately off-axis gas flow. The improvement in 3 sigma uniformity from ~2% to 1% in Example 1 is significant. Example 3 indicates that the standard deviation in CD variation (pre - post etch) is reduced from 2.1 nm to 1.6 nm for the predominately off-axis gas flow setting. These test results demonstrate that the claimed plasma processing system, which allows the gas flow ratio between the on-axis and off-axis outlets to be changed for different steps of a multi-step process, can thus provide optimized process uniformity for each such step of a multi-step process.

10. In contrast, because the Ni gas injector shown in Figures 1 and 3A-3C does not allow the gas flow ratio between the on-axis and off-axis outlets to be changed for different steps of a multi-step process, it cannot meet uniformity or customer standards for certain multi-step processes. For example, while the Ni injector can be designed to provide a mixed gas flow ratio that provides the results achieved in the process of Example 1, that same Ni gas injector would not be able to

also provide optimized process results for the processes of Examples 2 and 3, for which predominately off-axis flow conditions provided the best process uniformity. Assuming alternatively that the Ni injector can be designed to provide predominately off-axis gas flow that provides the process results achieved for the processes of Example 2 and 3, the same Ni injector would not be able to also provide optimized process results for the process of Example 1, for which predominately off-axis flow conditions provided the worst process uniformity.

11. The Examples demonstrate that the particular flow ratio of the gas flows provided from the on-axis and off-axis gas outlets, i.e., predominately off-axis flow, predominately on-axis flow, or mixed on-axis and off-axis flow, that provides the most desirable results for a given step of a multi-step etch process for a semiconductor substrate can be substantially different from the flow ratio of the gas flows that provides the most desirable plasma etch results for a different step of the multi-step etch process. For this reason, the Ni gas injector shown in Figure 1 and Figures 3A-3C is impractical for use in a plasma processing chamber for a multi-step etch process.

12. I have reviewed U.S. Patent No. 5,532,190 ("Goodyear") and note that there is a discussion in the Background section of Goodyear of the problem of lack of uniformity for plasma deposition or etching using the same gas source for a multi-zone showerhead. Goodyear solves this problem by using different gas sources for the two zones of a multi-zone showerhead. In contrast, the claimed injector can achieve uniformity using the same gas source.

13. It is my opinion that one having ordinary skill in the art would not have considered prior art showerhead electrodes in the design of an injector for an inductively-coupled (ICP) plasma processing system. Showerhead electrodes are conductive and cannot be located beneath an inductive coil of an ICP reactor. Also, showerhead electrodes are typically used in capacitively-coupled plasma processing chambers (parallel-plate reactors), which typically have different plasma density and chamber pressures than ICP reactors. Showerheads are also designed to operate in a fundamentally different manner and provide fundamentally different gas flow characteristics than the claimed injector. Showerheads typically include a large number of gas injection holes, e.g., at least 1000 holes. These holes are typically all parallel to each other, i.e., all "on-axis." In addition, showerheads are typically located close to wafers in plasma processing chambers. For example, the showerhead / wafer gap is typically about 2-2.5 cm in capacitively-coupled chambers. The gas injector / wafer gap is typically about 15 cm in an ICP plasma processing chamber for processing 300 mm wafers. Regarding gas flow, because a showerhead includes many holes, the gas exit velocity is normally sufficiently low that diffusion becomes the dominant transport mechanism. In a parallel plate reactor with a relatively narrow gap the gas distribution pattern is fairly well localized to the hole pattern, and the relative flow from each orifice. Moving a showerhead further and further from the wafer (such as to the wafer / injector distance typically used in an ICP) would make the inner and outer regions at the wafer less well correlated to the showerhead zones. This result would occur because gas leaving the showerhead would diffuse more and more in the plane parallel to the electrode before reaching the wafer as the wafer / showerhead distance is increased. In

contrast to a capacitively-coupled chamber, an ICP chamber typically has a substantially larger injector / wafer gap and gas flow is not localized simply to on-axis holes. In an ICP chamber, the supply and exhaust from the entire chamber volume also need to be considered. The higher flow rate from a smaller number of holes for the claimed gas injector allows for more controlled directivity from the injector. Thus, due to these fundamental differences, one having ordinary skill in the art would not have considered prior art showerhead electrodes in the design of an injector for an ICP system.

14. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: 6/6/2006

David J. Cooperberg

contrast to a capacitively-coupled chamber, an ICP chamber typically has a substantially larger injector / wafer gap and gas flow is not localized simply to on-axis holes. In an ICP chamber, the supply and exhaust from the entire chamber volume also need to be considered. The higher flow rate from a smaller number of holes for the claimed gas injector allows for more controlled directivity from the injector. Thus, due to these fundamental differences, one having ordinary skill in the art would not have considered prior art showerhead electrodes in the design of an injector for an ICP system.

14. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Date: ____________________ ________________________________

David J. Cooperberg

David Cooperberg

Professional Portfolio

EDUCATION

University of California at Berkeley, Berkeley, CA.
Ph.D. in Physics, January 1998
Dissertation: Modeling and Simulation of High Frequency Surface Waves in Bounded Plasmas

Cornell University, Ithaca, NY.
B.S. with Distinction in Applied and Engineering Physics, May 1990

RESEARCH AND WORK EXPERIENCE

Aug. 1997 - Present Modeling and Sr. Process Engineer
Lam Research Corporation, Fremont, CA

* Designed, implemented, and maintained a semi-empirical profile simulator for modeling feature evolution during plasma processing of integrated circuits. Used profile simulator and experimental results to develop semi-quantitative models for feature evolution in polysilicon gate, STI, photoresist trim, deep silicon trench, and contact etch process, and I-PVD of Cu.

* Provided electromagnetics, fluid dynamics, and plasma discharge modeling support for product development using commercial, university, and internally developed codes. Key contributions made in design of coils for inductively coupled plasma (ICP) reactors, dual zone gas injector, gas distribution baffles, electrode edge rings, uniformity rings, magnetic and RF shielding, and microwave applicator.

* Performed experimental study of plasma etching of patterned aluminum films which included Langmuir probe, OES, SEM, and profilometric analyses and used results along with reactor scale modeling to develop a calibrated profile evolution model with predictive capability to assist in process development.

* Developed algorithms for interferometric endpoint system. Designed and implemented code for rapid testing of endpoint algorithms based on broadband reflectance from patterned wafers.

Sep. 1992 - Aug. 1997 Research Assistant
University of California at Berkeley, Electronics Research Laboratory

* Conducted study of surface waves in bounded cylindrical and planar plasmas via numerical simulation.
* Measured real and imaginary dispersion relations. Verified existence of surface waves having cutoff frequencies defined by ``Tonks-Dattner" resonances.
* Modeled surface wave sustained discharges in one and two dimensional bounded plasmas. Characterized these discharges by finding scaling laws, plasma impedance, wave and electron heating profiles, and electron energy distribution functions.

* Adapted and maintained electrostatic and electromagnetic Particle-in-Cell Monte-Carlo-Collision (PIC-MCC) bounded plasma simulation codes. Modifications included the design and implementation of a variable particle weight scheme in argon and oxygen MCC packages to assist electro-negative discharge simulation and reduce computation time, the addition of electromagnetic and periodic field solving algorithms, and creation of numerous diagnostics in wk-space.
* Co-authored XGRAFIX, a graphical user interface, which runs under Unix/X Windows and provides a flexible frontend for viewing and manipulating output and controlling simulation codes.

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D. J. Cooperberg, S. Johnston, D. Horak, V. Vahedi, "Surface and Reactor Dynamics Governing Photoresist Trim and Organic BARC Open Plasma Processing," 50th American Vacuum Society International Symposium, Baltimore, MD, November 2-7, 2003.

V. C. Venugopal, A. J. Perry, K. V. Wallace, D. J. Cooperberg, "Manufacturability considerations in designing optical monitoring methods for control of plasma etch processes", Proceedings of SPIE -- Volume 5188 Advanced Characterization Techniques for Optics, Semiconductors, and Nanotechnologies, Angela Duparre, Bhanwar Singh, Editors, November 2003, pp. 200-211

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